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Study of the global hydrodynamics and gas-liquid transfer in a thin-gap bubble column

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Introduction

The cultivation of microalgae in photobioreactors (PBR) is a process that knows a strong infatuation in recent years because of its many fields of application (energy, green chemistry, food supplement, etc.). Use of low optical thickness (few millimeters) photobioreactors allows intensifying the volumetric productivity by increasing the concentration of microalgae. Therefore, the amount of water used decreases. This causes a reduction in production, agitation and harvesting costs [1]. These low thickness reactors are called "high volume productivity photobioreactors". Technologies already exist to meet the objective of high cell concentrations. Among these, the Algofilm technology is based on a falling film of small thickness which flows over a smooth surface, exposed to the solar light [2], [3]. Another technology consists in a vertical photobioreactor of small thicknesses ($e < 7\text{mm}$) [4], operating in a bubble column mode. Bubble columns are indeed commonly used as they allow to circulate the culture and to ensure the gas-liquid transfers necessary for the growth of microorganisms.

The present study focuses on this last type of thin gap bubble column. Hydrodynamics of gas-liquid reactors is known for its complexity: deformability of the bubbles, breaking and coalescence phenomena, existence of various flow regimes that are not easy to predict. It is important to characterize and predict the operating conditions of gas-liquid reactors, because the hydrodynamic behavior and transfer are different from one regime to another. The characterization of hydrodynamics in confined environments has little been dealt in the literature. [5], [6]. Hydrodynamics in a thin-gap bubble column appears as a key element, rendered specific by the strong confinement (interaction of bubbles with the walls), and possible increase the viscosity of the liquid phase due to high cell concentration [4]. Potential problems such as reduced mixing capabilities, poor gas-liquid mass transfer or biofilm development can also appear.

Objective

The aim of this work is to characterize the global hydrodynamics and gas-liquid mass transfer in an intensified vertical photobioreactor technology of reduced thickness (4 mm). Concerning hydrodynamics, the evolution of the void fraction with the superficial gas velocity is determined, this allows to characterize the different flow regimes; mixing is evaluated from mixing time determination based on tracing experiments. The gas-liquid mass transfer is quantified via kLa measurements and its evolution with the gas superficial velocity is analyzed. All these experiments are conducted for model fluids of different viscosities, mimicking different cell concentrations of microalgae. The terminal velocity of a single bubble in the confined column is also determined since it allows to explain some characteristics of the global hydrodynamics. All these results are compared to literature results for conventional bubble columns.

Results and conclusion

The evolution of the global gas hold-up with increasing superficial gas velocity, determined via static pressure measurements, is plotted in Figure 1 for the air-water system. It is compared to values obtained in a more conventional parallelepipedic bubble column of 4 cm thickness [7]. Regime transitions are also put into evidence in this figure. At low superficial gas velocities, the gas hold-up is slightly higher than for classical bubble columns. This can be explained by the terminal velocity in the thin-gap bubble column which is reduced by 30% to 50% compared to conventional bubble columns. So the residence time of the bubbles is higher in the homogeneous regime (before coalescence of bubbles). In fact, due to the significant confinement, the bubbles will undergo more friction. This will have an influence on the residence time of the bubbles in the column and thus on the gas hold-up. Beyond a certain superficial gas velocity, the gas hold-up is lower than that obtained for classical bubble column. This is due to the fact that in the case of this study, the transition and heterogeneous regimes appear at lower superficial velocity (U_g) (Figure I).

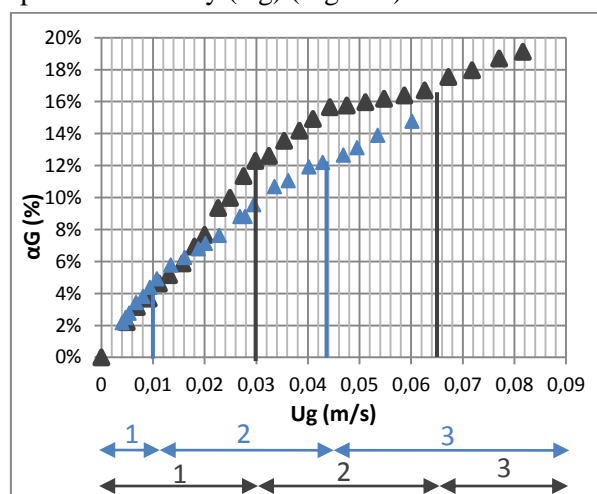


Figure 1 : Comparison between this application (▲) and the classical rectangular section bubble column used by Olmos [7] (▲). 1; 2; 3 are respectively homogeneous, transition and heterogeneous regime.

Concerning the gas-liquid mass transfer, from a superficial gas velocity of 0.02 m/s, it is lower than in classical bubble columns. This can be explained by Higbie model that links gas liquid mass transfer (kLa) to the exposure time between a liquid element and a gas bubble. In the confined bubble column, the drag coefficient is more important, so terminal velocity of bubbles is lower. Thus, the exposure time is higher and which decreases the gas-liquid mass transfer coefficient.

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